Seabed Variability and its Influence on Acoustic Prediction Uncertainty

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LONG TERM GOALS

The long term goal is to assess and characterize uncertainty in the tactical naval environment. The focus is on the contribution of seabed variability to uncertainty in sonar performance predictions. In littoral warfare, the seabed is often a controlling factor in sonar system performance.

OBJECTIVES

The specific objectives of this effort are to characterize the spatial variability of the seabed geoacoustic properties using remote acoustic methods and determine the uncertainties and errors associated with the estimation of the geoacoustic properties. In FY03 the objective was to develop the tools to describe how uncertainties propagate from remote acoustic measurements to meso-scale geoacoustic uncertainty and thence to system performance uncertainty.

APPROACH

The approach was broken into three main task areas: 1) characterize the uncertainties in the remote acoustic methods (in particular the seabed reflection measurements), 2) propagate those uncertainties to geoacoustic properties and 3) demonstrate how the geoacoustic uncertainties propagate to uncertainty in system performance measures. The main efforts were placed in tasks 1 and 2. In addition, modeling and analysis of seabed variability data were continued on the New Jersey shelf (STRATFORM) and the Malta Plateau.

WORK COMPLETED

A thorough uncertainty analysis was conducted for the seabed reflection technique. The agreement of the uncertainty estimates from a theoretical/modeling approach and an experimental approach indicated that the method and tools developed for uncertainty analysis are robust.

The transfer of measurement uncertainty to geoacoustic uncertainty was studied in considerable detail. The geoacoustic uncertainties from the above-mentioned theoretical/modeling approach agreed well with other methods of estimating uncertainty, again lending credence to the methods/tools. Finally the role of geoacoustic uncertainty on uncertainty in system performance was explored using an idealized model.

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RESULTS

The dominant contribution to the uncertainty in the measured reflection coefficient is the variability of the source amplitude due to non-constant drag forces on the source plate and catamaran; ping-to-ping variability under tank conditions is quite small. A new normalizing processing approach was developed to help minimize effects of source variability. Specific uncertainty estimates depend upon frequency, experiment geometry, sea state and well as several other minor factors, but a typical standard deviation of the reflection loss ($-20 \log_{10}|R|$) is ±0.5-1 dB. The uncertainty can be reduced by trading-off variance with angular resolution. It was demonstrated that averaging over 1º window can reduce the standard deviation by about one half.

Equations for the uncertainty associated with the angle estimates were derived that provide angle uncertainties as a function of experimental and environmental uncertainties [1]. The part of the angular range that is the most crucial for minimizing errors is dictated by the critical angle, since this angle controls long-range propagation. Ref [2] indicates that for unconsolidated sediments on the continental shelf, critical angles vary from 0-34º. In that range the seabed reflection angle uncertainty is predicted to be quite small, from about ±0.01-0.3º (see Fig 1). At normal incidence, the errors are considerably larger, however, the increase in errors are mitigated by the fact that the reflection coefficient itself is often nearly constant between 70-90º.

Uncertainty was also estimated experimentally. Multiple measurements of the seabed reflection coefficient were taken at the same location (within several hundred meters) but at different times and under different experimental conditions. The variation in position of the peak (at 25º) and nulls (at 32º) of the reflection loss from the various measurements were used to estimate the uncertainty. The experimentally derived estimates ('+' in Fig 1) agree quite well with those estimated theoretically.

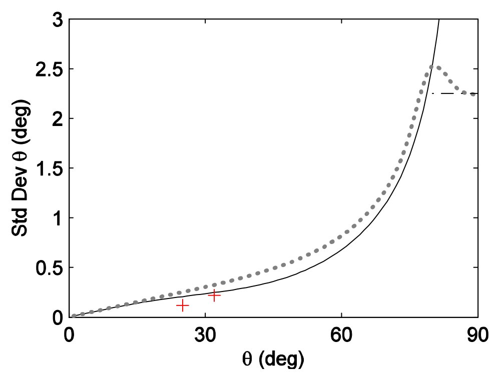

Figure 1. Estimates of uncertainty in reflection angle at the seabed from theory (solid and dashed black lines), from simulation (gray dashed line) and from multiple measurements at nearly the same location (+).

A crucial part of the uncertainty DRI is concerned with the transfer of uncertainties. A Bayesian approach was used (with Stan Dosso [3]) to determine how the uncertainties in the seabed reflection transfer or propagate to uncertainty in the geoacoustic properties. This fully non-linear approach describes the uncertainties in the geoacoustic properties as well as the inter-parameter coupling via the posterior probability density (PPD) function. Fig 2 shows the marginal PPD from an inversion on

reflection data in the Straits of Sicily. There are several salient points. First of all, the uncertainties using the theoretical experimental errors (discussed in the preceding paragraphs) give consistent results with other commonly used methods for uncertainty estimation, giving further credence to the data uncertainty estimation. Second, note that the compressional speed and density are estimated to fairly high accuracy (± 2 m/s and ± 0.02 g/cc respectively) while the shear speed and attenuation are poorly constrained by the data. That is to say, that the shear properties play a minimal role in seabed reflection for this kind of soft sediment (silty-clay).

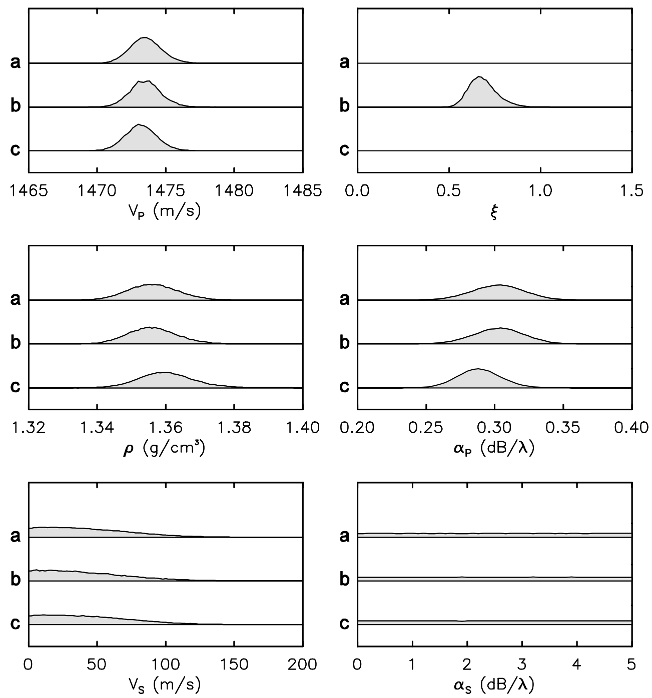

Figure 2. Marginal probability distributions for uncertainty estimation using a) maximum likelihood scaling, b) fast Gibbs sampling standard deviation scaling and c) using theoretically estimated experimental errors. The geoacoustic parameters are sediment compressional and shear speed (Vp and Vs), density (ρ), compressional and shear wave attenuation (α_p and α_s).

The geoacoustic properties from such inversions are important inputs for propagation, reverberation and system performance models. In order to determine how the uncertainty further propagates to system performance models, an analytic model [4] for signal-to-reverberation ratio (SRR) in a Pekeris waveguide was employed in conjunction with the PPD from an inversion for boulder clay [5]. Fig 3 shows the SRR cast as a probability distribution considering uncertainty in the geoacoustic properties. Typically, the SRR is given as a single number (SRR is independent of range if the scattering strength follows a Lambert's Law [4]) probability distribution). However, a probability distribution may be a more meaningful metric than a single number.

In order to determine which geoacoustic uncertainty was the most significant factor controlling the SRR distribution, the SRR distribution was calculated with all of the uncertainties present (see Fig 3a) and then with each parameter fixed at its mean and the other parameters allowed to vary across the PPD. The analysis indicates that (for this PPD) the total uncertainty in the signal-to-reverberation ratio (due to seabed geoacoustic properties) is dominated by uncertainties in the attenuation. While this will

certainly not hold for every environment, an approach has been demonstrated for how to describe and transfer measurement-to-geoacoustic-to system performance uncertainties.

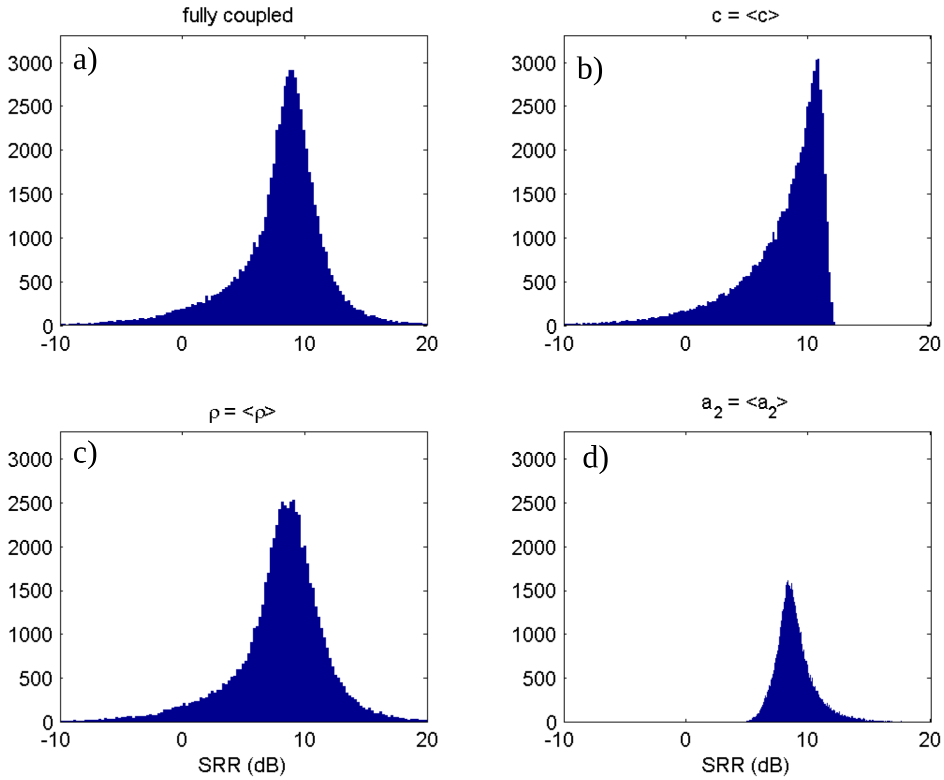

Figure 3. Signal-to-reverberation ratio (SRR) distribution for geoacoustic uncertainties – the geoacoustic uncertainties are expressed as a PPD, a) all geoacoustic uncertainties, b) all geoacoustic uncertainties except sound speed, c) all geoacoustic uncertainties except density, d) all geoacoustic uncertainties except attenuation.

IMPACT/APPLICATIONS

The results of this work demonstrates a viable approach for capturing, characterizing and transferring uncertainty from remote measurements of the seabed through the geoacoustic properties and on to a measure of active system performance. We have proposed using a probability density function approach for transferring uncertainty. This approach needs to be examined by other researchers in the DRI, particularly in the end-to-end teams. While the focus here has been on the seabed, clearly there are other sources of uncertainty (e.g., the oceanography and target) that need to be incorporated into the analysis.

RELATED PROJECTS

ONR GeoClutter: Providing high resolution acoustic and geoacoustic data required for estimating seabed spatial variability and uncertainty on the New Jersey shelf.

Boundary Characterization Joint Research Project ONR-NATO SACLANT Centre: Providing high resolution acoustic and geoacoustic data required for estimating seabed spatial variability and uncertainty estimates in the Straits of Sicily and the Tuscany Shelf.

ONR SWAT Program: Collaborating on geoacoustic findings on the New Jersey Shelf.

REFERENCES

[1] Holland, C.W., Seabed Reflection Measurement Uncertainty, J. Acoust. Soc. of Am, (in press).

[2] Hamilton, E.L., "Geoacoustic modeling of the seafloor," J. Acoust. Soc. Am., 68, 1313-1339, 1980.

[3] Dosso, S. E. and Holland, C.W., "Geoacoustic uncertainties from inversion of seabed reflection data," J. Acoust. Soc. of Am., in review.

[4] Harrison, C.H., "Signal and reverberation with mode-stripping and Lambert's Law," SACLANT Undersea Research Centre, La Spezia, Italy, SR-356, 2002.

[5] Riedel, M., Dosso, S. and B. Laurens, "Uncertainty Estimation for AVO Inversion, Geophysics, in review.

PUBLICATIONS

Holland, C.W., Seabed Reflection Measurement Uncertainty, J. Acoust. Soc. of Am, [refereed, in press].

Dosso, S. E. and Holland, C.W., "Geoacoustic uncertainties from inversion of seabed reflection data," J. Acoust. Soc. of Am. [submitted].

Holland, C.W., and C. Harrison, Measurement of the Seabed Reflection Coefficient in Shallow Water: A comparison of two techniques, in International Conference on Theoretical and Computational Acoustics, August 2003 proceedings.